TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 420

THE EFFECT OF PROPELLERS AND NACELLES ON THE LANDING SPEEDS OF TRACTOR MONOPLANES

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SUMMARY

This paper reports wind-tunnel tests giving the lift coefficients of large-scale wing-nacelle combinations both with and without the propeller. The tests were made to show the effect of nacelles, and idling and stopped propellers on the landing speeds of tractor monoplanes. Four types of nacelles with various cowlings were used in numerous positions with respect to both a Clark Y and a thick airfoil.

The effect of both the idling and stopped propeller on lift, and consequently on landing speed, was negligible.

A nacelle with exposed engine cylinders when placed directly in front of an airfoil caused a slight reduction in lift, consequently an increase in landing speed, over the condition with the wing alone. With this exception no appreciable effect on landing speed was indicated for any of the other combinations.

INTRODUCTION

Reports have been received recently that some of the trimotored transports land at much higher speed than the designers estimated. One explanation which has been advanced is that idling or stopped propellers have an adverse effect on the lift of the wings. The interference of uncowled engines has also been suggested as a possible explanation.

This paper presents certain results, extracted from a recently completed general research on wing, nacelle, and propeller interference, which show the effect on landing speed of idling and stopped propellers, of the position of the nacelle with respect to the wing, and of the type of cowling. Although the landing speed is usually considered a function of the lift coefficient only, in practice the actual landing speed is also dependent upon such other factors as control and stability which may be affected by the propeller and nacelle. In this paper these other factors are neglected and only the effect of the propeller and nacelle on landing speed as a function of lift coefficient is considered. Results are given for two monoplane wings of different thickness/chord ratios.

APPARATUS

The tests were made in the propeller-research tunnel of the National Advisory Committee for Aeronautics at Langley Field, Va. A description of the tunnel and its regular facilities for testing may be found in reference 1. Figure 1 shows the general arrangement of the apparatus and reference 2 fully describes the method of mounting. Figure 2 shows the arrangement of the nacelle-airfoil positions, gives their designations, and the relative sizes of the two airfoils. A description of the dummy engine and the method of driving the 4-foot propeller are given in detail in reference 3 which describes the main series of tests from which the data contained herein are taken.

The thinner airfoil shown in Figures 1 to 9, inclusive, is a standard Clark Y section (thickness/chord ratio of 0.117) of aspect ratio 5 having a span of 15 feet 10 inches and a chord of 3 feet 2 inches. All coefficients for combinations with this airfoil were based on a wing area of 50 square feet.

The thick airfoil (thickness/chord ratio of 0.200) is shown in Figures 2, 10, 11, and 12. This airfoil section approximates that of the wing of the Fokker trimotored transports at the same span location as the engine nacelles. Since the chord of a typical trimotored airplane wing is approximately 5 feet when scaled down in the same proportion as the 4-foot propeller, this airfoil was therefore made with a chord of 5 feet. This chord, together with the span of 15 feet, gives a wing area of 75 square feet which was used to compute all coefficients for combinations with this airfoil. Although the aspect ratio of 3 is low the results are considered to be satisfactory for comparative purposes for the span is believed to be large enough to include all the interference between the airfoil, nacelle, and propeller and is still within the effective diameter of the air stream (20 feet).

The four nacelles are as follows: a streamlined one and three with a dummy wooden model of a J-5 engine 4/9 scale.

Nacelle No. 1 is streamlined, of cast aluminum, and shown in Figures 1, 8, and 9.

Nacelle No. 2 is shown in Figure 3 and is similar to conventional types which leave slightly more than half of the fin area of the cylinders exposed.

Nacelle No. 3 is nacelle No. 2 with an N.A.C.A. hood over the cylinders as shown in Figures 4 and 5.

Nacelle No. 4 is a completely cowled nacelle of the N.A.C.A. type and shown in Figures 6 and 7.

The propeller is a 4-foot, adjustable-pitch metal propeller geometrically similar to the 9-foot Navy propeller No. 4412. It is designated No. 4412 - 4 ft.

TESTS

The general investigation of wing, nacelle, and propeller interference showed the effect on lift coefficient of the following factors: an idling propeller with pitch settings of from 12° to 27° at 75 per cent of the radius; the effect of a propeller with pitch settings of 17° and 22° at 75 per cent radius stopped in both the horizontal and vertical position; four nacelles in various positions with respect to the Clark Y airfoil; and three of the nacelles in various positions with respect to the thick airfoil.

In the course of the general investigation, because of the close agreement of certain of the data, it was found possible to eliminate a large number of the combinations that would have been required to investigate completely the entire subject. As a result the data extracted for this study of the effect of propeller and nacelle on landing speed are not exactly parallel for all of the various combinations employed, although they are believed to be sufficiently so for the purpose intended.

Tests of combinations in which the Clark Y airfoil was used were made at angles of attack of -5°, 0°, $+5^\circ$, $+10^\circ$, and $+15^\circ$; and those in which the thick airfoil was used were made at angles of attack of -5°, 0°, $+5^\circ$, $+10^\circ$, and $+12^\circ$. Tests with the propeller operating at various values of V/nD were made with all of the combinations, and those with the propeller stopped with only a few of the combinations. Force tests of the airfoils alone were made at the above-mentioned angles of attack to serve as a basis of comparison in finding the effects of the different nacelles. With each combination of wing, nacelle, and propeller, tests were made with the propeller removed to serve as a basis of comparison for propeller effect.

RESULTS

For the purpose of discussion the results have been separated to show the effect on lift of the following three factors: idling propeller (Table I and figs. 13 and 14), stopped propeller (Tables II and III and fig. 15), and nacelles (Table IV and figs. 16 and 17). These results are presented in the form of the standard nondimensional coefficients C_L, C_T, and V/nD.

Tables I, II, and III give the change in lift occasioned by propeller conditions from that with propeller removed. Table IV gives the change in lift occasioned by the different nacelles (with propeller removed) from that of the airfoil alone. By the proper combination of the results given in Tables I, II, and III with those given in Table IV, the change in lift due to any one variable (propeller condition, nacelle, or nacelle position) or any combination of them may be obtained.

All results are given for a dynamic pressure of 25.6 pounds per square foot, corresponding to an indicated velocity of 100 miles per hour. The Reynolds Number for the Clark Y combinations is approximately 2,700,000, which could be attained by using a wing having a chord of 7 feet $1\frac{1}{2}$ inches in combination with a J-5 engine and 9-foot propeller at 44.5 miles per hour. The Reynolds Number for the thick-wing combinations is approximately 4,300,000, which could be attained by using a wing having a chord of

11 feet 3 inches with the same engine and propeller combination (J-5 engine and 9-foot propeller) at the same speed (44.5 m.p.h.).

Aspect ratio and tunnel-wall corrections have not been made as the results are intended for comparative purposes only. The results are believed ~~accurate~~ precise to ±4 per cent for the test points and ±2 per cent for the faired curves at the higher values of lift coefficient.

DISCUSSION

The equation for lift coefficient in level flight is

$$C_L = \frac{W}{\frac{1}{2}\,\rho\,V^2\,S} \quad \text{or} \quad V = \sqrt{\frac{2\,W}{C_L\,\rho\,S}}$$

where C_L, absolute lift coefficient

W, weight of the airplane

ρ, mass density of the air

S, wing area

V, speed of airplane

It is seen that the landing speed varies inversely as the square root of the lift coefficient, if all other factors remain constant. Therefore, landing speed is not very sensitive to changes in lift, a 10 per cent drop in lift coefficient causing about a 5 per cent increase in landing speed, which would mean a 2.5 mile per hour increase at 50 miles per hour. An increase in landing speed from 50 to 60 miles per hour would necessitate a decrease of approximately 30 per cent in the lift coefficient.

The discussion is given for 15° angle of attack for the Clark Y airfoil and 12° for the thick airfoil. These angles were selected as being more representative of actual landing conditions than the angles of attack of maximum lift (18° and 15°, respectively) because it is questionable whether the average landing is made or can be made at an angle as high as that for maximum lift.

Effect of Idling Propeller

The idling condition depends upon the pitch and rotational speed of the propeller and the speed of the airplane. Average landings are probably made with the propeller operating between zero thrust and zero power so long as the engine is running under its own power. The condition of negative power (propeller acting as a windmill and supplying power to rotate the engine crankshaft) is not considered in this paper.

An examination of the data showed that there was only a small change in lift between zero effective thrust and zero power (figs. 13 and 14) and therefore tables are given for one condition only; namely, zero effective thrust. The difference in lift as shown in Figures 13 and 14 was the maximum encountered. With the majority of the combinations tested there was practically no difference in lift between the two conditions. With the exception of one position (B-1-A) with the Clark Y airfoil the change in lift due to the idling propeller would not affect the landing speed over $1\frac{1}{2}$ per cent for the Clark Y airfoil or 3 per cent for the thick airfoil. (See Table I.) In the majority of cases the effect would be to decrease the landing speed. Position B-1-A will be considered again in the discussion on effect of nacelles.

Effect of Stopped Propeller

The effect of pitch and position of a stopped propeller is small and is given in Table II and Figure 15 for several nacelle positions and cowlings in combination with the Clark Y airfoil. The maximum variation in landing speed corresponding to the changes in lift found for these conditions is from about 3 per cent increase to $1\frac{1}{2}$ per cent decrease. Table III gives the change in lift coefficient for some additional combinations with the Clark Y airfoil as well as for some with the thick one. Tables I, II, and III have approximately the same range of values and the effect of the stopped propeller is approximately the same as that of an idling one. Although the stopped propeller was not tested with as many combinations as the idling one, it is believed that a sufficient number were tested to show the maximum effect.

Effect of Nacelles

With the exceptions of positions B-1-A with the Clark Y airfoil and nacelle No. 2 (exposed cylinders) located in line with and ahead of the wing (position B) the change in landing speed caused by adding a nacelle to a wing was $4\frac{1}{2}$ per cent or less. With nacelle No. 2 in position B the lift was reduced about $12\frac{1}{2}$ per cent with the Clark Y and 16 per cent with the thick airfoil, corresponding to increases in landing speed of approximately 7 and 9 per cent, respectively.

The results obtained at position B-1-A with the Clark Y airfoil are peculiar. Table IV shows that adding a nacelle to the airfoil reduces the lift to a marked degree and by combining the values in Tables I and IV it may be seen that if the propeller is idling the lift is brought up to within about 7 per cent of that of the airfoil alone. Hence with an idling propeller (actual landing condition) in this position the landing speed would be only about $3\frac{1}{2}$ per cent higher than with the airfoil alone; whereas, with the propeller removed the landing speed might be 11 per cent higher. Erratic test points for this position at the higher angles of attack leads one to suspect an unstable air flow. This position is also an undesirable location for a nacelle from the standpoint of interference drag. (See reference 3.)

Comparison with Other Tests

In some recent tests (reference 4) the British Aeronautical Research Committee found a maximum increase of 5 per cent in landing speed for a position with a nacelle in line with the wing but with the propeller considerably closer to the wing than the closest position of these tests. The propeller had approximately 27° blade angle at 75 per cent radius and the ratio of propeller diameter to wing chord was larger than in the tests described herein. Allowing for these differences in test conditions, the results are in fair agreement.

CONCLUSIONS

In so far as the landing speed of a tractor monoplane is a function of the lift it is not materially affected by either an idling or stopped propeller or by a nacelle and wing in combination, except where a nacelle with exposed engine cylinders mounted directly ahead of the wing is employed. In such a case an increase in landing speed of 7 to 9 per cent is indicated.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., April 7, 1932.

REFERENCES

1. Weick, Fred E., and Wood, Donald H.: The Twenty-Foot Propeller Research Tunnel of the National Advisory Committee for Aeronautics. T.R. No. 300, N.A.C.A., 1928.

2. Wood, Donald H.: Tests of Large Airfoils in the Propeller Research Tunnel, Including Two with Corrugated Surfaces. T.R. No. 336, N.A.C.A., 1929.

3. Wood, Donald H.: Tests of Nacelle Propeller Combinations in Various Positions with Reference to Wings. Part I. Thick Wing - N.A.C.A. Cowled Nacelle - Tractor Propeller. T.R. No. 415, N.A.C.A., 1932.

4. Perring, W. G. A., and Callen, C.: The Influence of a Stopped Airscrew on the Lift and Drag of an Aerofoil. R. & M. No. 1347, British A.R.C., 1930.

TABLE I

EFFECT OF IDLING PROPELLER ON LIFT COEFFICIENT

Prop. No. 4412 – 4 ft. – Set 17° at 0.75 R

(C_L with Propeller Operating at Zero Effective Thrust Minus C_L without Propeller)

(+) Increase, (–) Decrease in C_L

Nacelle	Clark Y airfoil, $\alpha = 15^\circ$							Thick airfoil, $\alpha = 12^\circ$			
	Nacelle position							Nacelle position			
No.	C-3-A	B-1-A	B	C	A-1-B	A-2-B	C-3-B	B-1-A	B	A-1-B	A-2-B
1	-0.027	(b)	0.033	0.002	(b)	0.009	-0.005	(b)	(b)	(b)	(b)
2	(b)	0.144	.012	(b)	0.002	.019	(b)	0.018	0.022	0.032	0.017
3	(b)	.043	.012	(b)	.013	.010	(b)	.023	-.002	.011	.008
[a]4	(b)	.124	-.008	(b)	.013	.025	(b)	.025	.005	(c)	.055
								.029	.003	.177	.068

(.009)

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(similarity used unfair?)

[a] Tested in all positions with airfoil No. 2.

[b] Not tested.

[c] Erratic.

TABLE II

EFFECT OF POSITION AND PITCH OF A STOPPED PROPELLER
ON LIFT COEFFICIENT
Clark Y Airfoil ~ $\alpha = 15^\circ$
(C_L with Propeller Stopped Minus C_L without Propeller)

(+) Increase, (-) Decrease in C_L

Nacelle No.	Nacelle position	Set 17° at 0.75 R		Set 22° at 0.75 R	
		Stopped hor.	Stopped vert.	Stopped hor.	Stopped vert.
1	C-3-A	-0.035	-0.039	-0.034	-0.037
	B	- .038	.013	- .026	.020
	C	- .029	- .016	- .042	- .033
	C-3-B	- .037	- .039	- .034	- .051
2	B	- .075	- .005	- .054	- .030
3	B	- .037	- .025	- .054	- .028
4	B	.027	.037	.035	.036

TABLE III

EFFECT OF STOPPED PROPELLER ON LIFT COEFFICIENT

Prop. No. 4412 - 4 ft. - Set 17° at 0.75 R - Stopped Vertically

(C_L with Propeller Stopped Minus C_L with Propeller Removed)

(+) Increase, (-) Decrease in C_L

Nacelle	Clark Y airfoil, α = 15°							Thick airfoil, α = 12°			
	Nacelle position							Nacelle position			
No.	C-3-A	B-1-A	B	C	A-1-B	A-2-B	C-3-B	B-1-A	B	A-1-B	A-2-B
1	-0.039	(b)	0.013	-0.016	(b)	-0.018	-0.039	(b)	(b)	(b)	(b)
2	(b)	(b)	-.005	(b)	(b)	- .030	(b)	(b)	-0.004	0.012	(b)
3	(b)	(b)	-.025	(b)	(b)	- .027	(b)	(b)	- .003	(b)	(b)
4	(b)	(b)	.037	(b)	(b)	- .014	(b)	[a]-0.005	[a]- .005	(c)	-0.052

[a] Set 22° at 0.75 R.

[b] Not tested.

[c] Erratic.

TABLE IV

EFFECT OF NACELLE COWLING AND POSITION ON LIFT
COEFFICIENT WITH PROPELLER REMOVED

(C_L of Combination Minus C_L of Airfoil Alone)

(+) Increase (-) Decrease in C_L

Nacelle No.	Clark Y airfoil, $\alpha = 15^\circ$, C_L airfoil alone = 1.196							Thick airfoil, $\alpha = 12^\circ$, C_L airfoil alone = ~~0.959~~ 0.960			
	Nacelle position							Nacelle position			
	C-3-A	B-1-A	B	C	A-1-B	A-2-B	C-3-B	B-1-A	B	A-1-B	A-2-B
1	0.002	(b)	-0.015	0.010	(b)	-0.013	0.008	(b)	(b)	(b)	(b)
2	(b)	-0.214	- .147	(b)	-0.082	- .012	(b)	-0.069	-0.153	-0.022	-0.009
3	(b)	- .116	- .004	(b)	- .072	- .003	(b)	- .003	.019	- .006	- .014
[a]4	(b)	- .153	- .049	(b)	- .104	- .029	(b)	.036 -.039 +.037	.044 .042	(c) -.176	- .048 -.052

[a] Tested in all positions with airfoil No. 2.

[b] Not tested.

[c] Erratic.

[illegible]

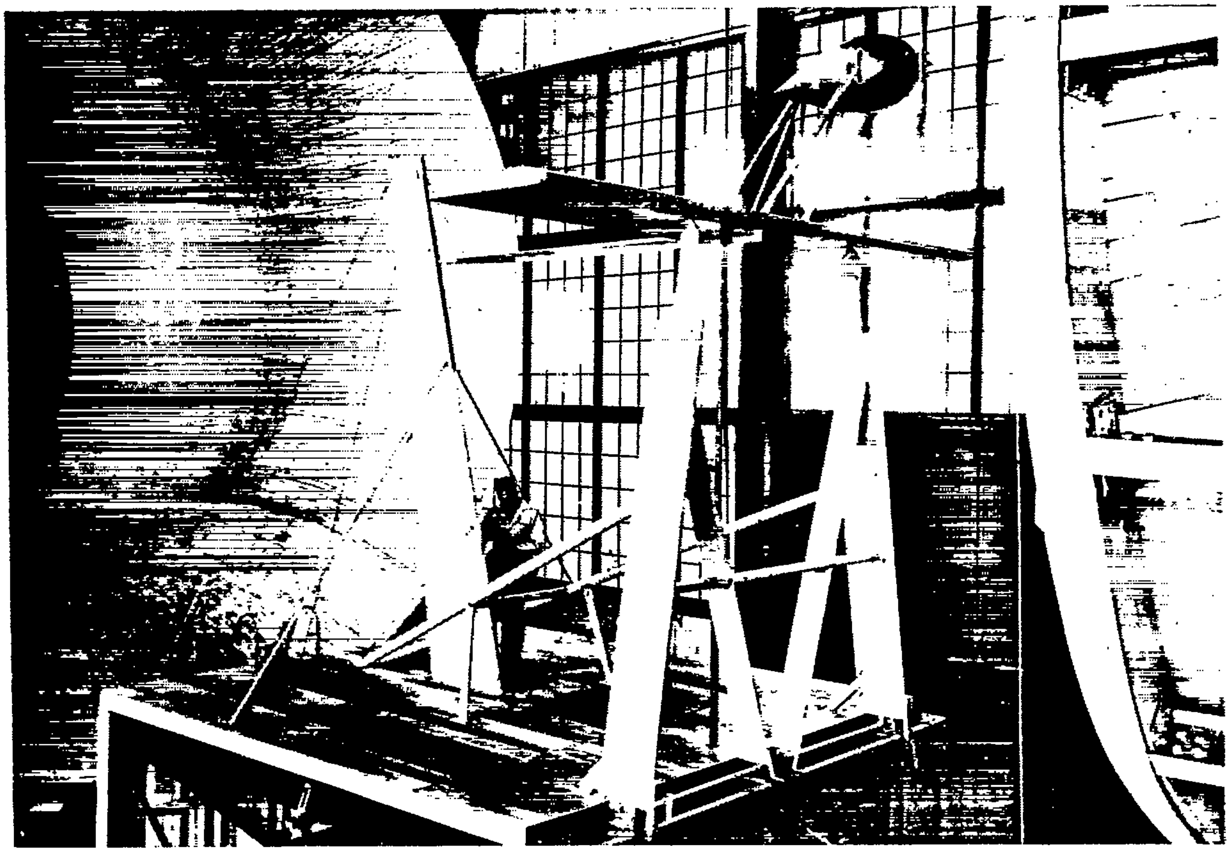


Fig.1 General arrangement of apparatus and method of mounting.

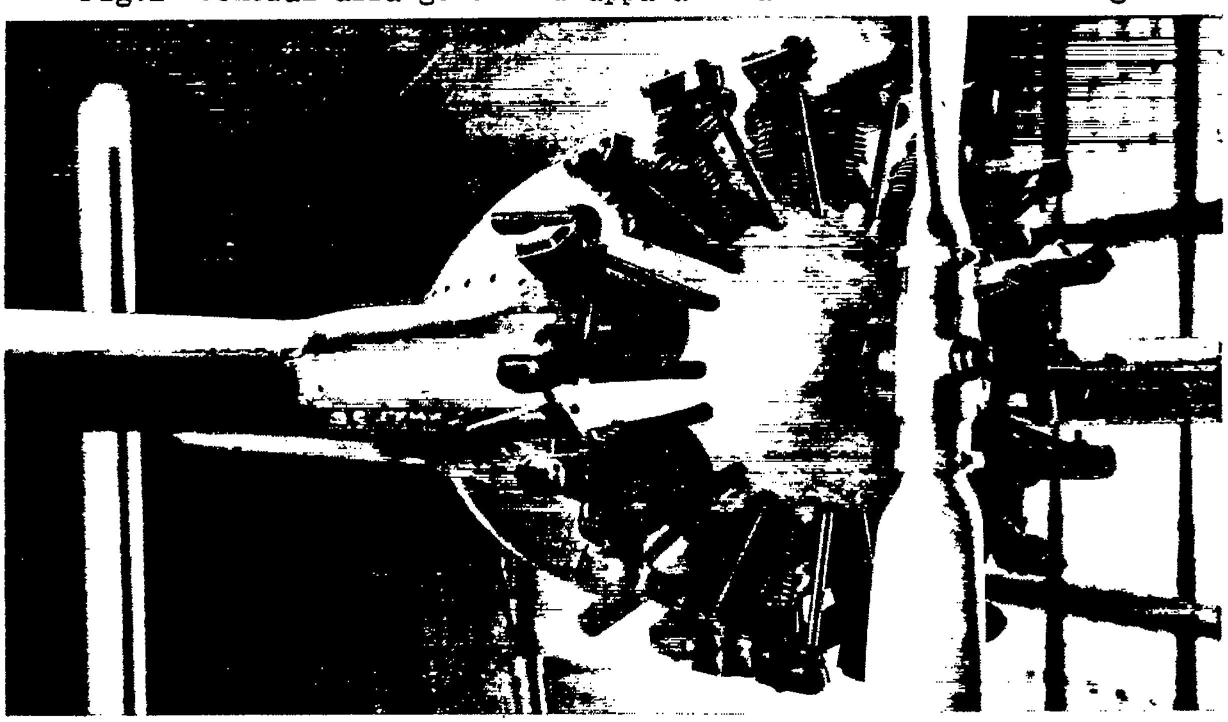


Fig.3 Photograph of model engine and propeller (Clark Y airfoil, Nacelle No.2, position B).

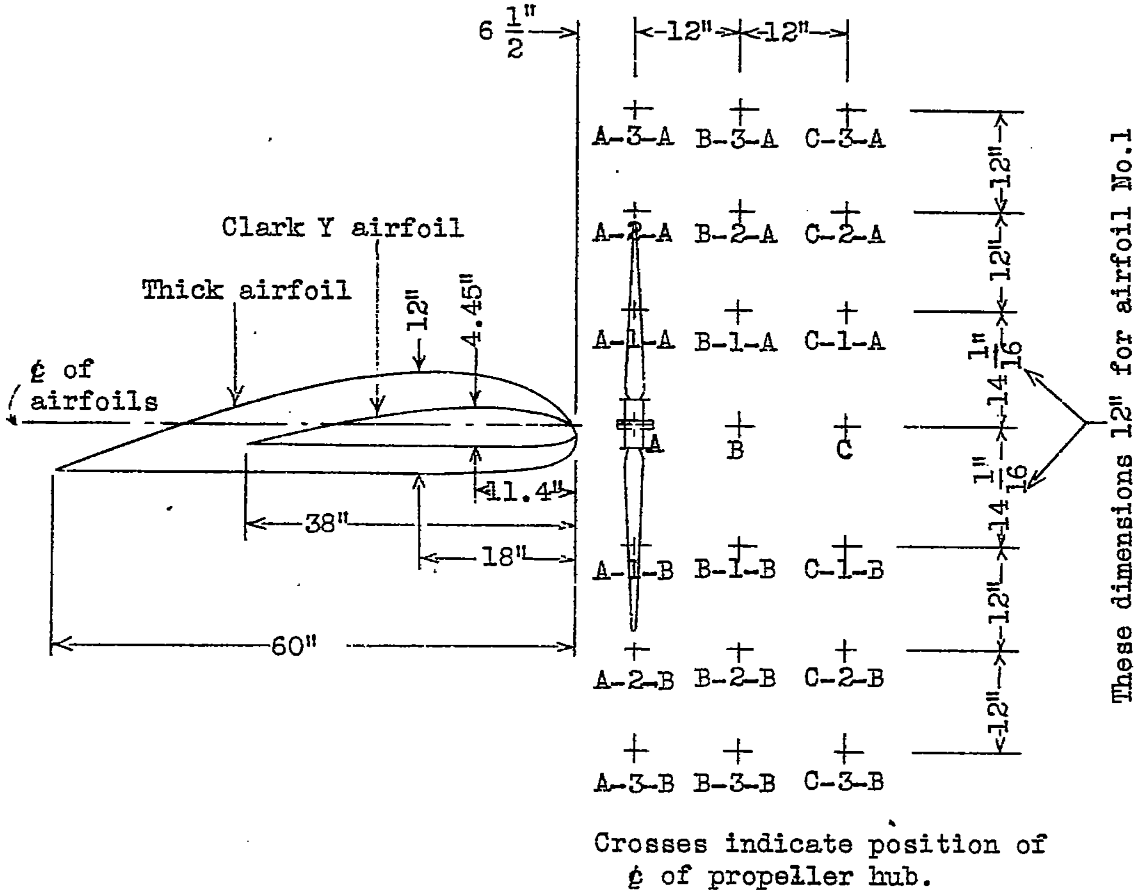


Fig.2 Diagram showing relative sizes of the two airfoils and propeller used and designation of nacelle positions.

Fig. 4 Clark Y airfoil. Nacelle No. 3. Position B.

Fig. 5 Clark Y airfoil. Nacelle No. 3. Position B.

Fig. 6 Clark Y airfoil. Nacelle No. 4. Position B.

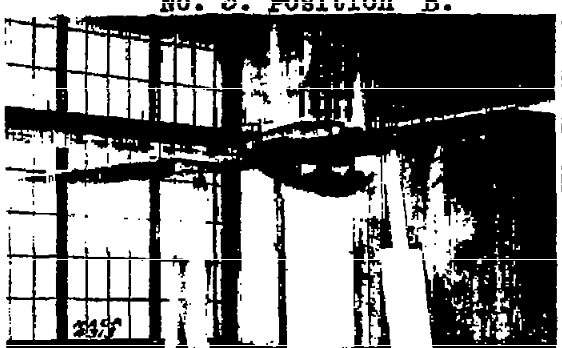


Fig. 7 Clark Y airfoil. Nacelle No. 4. Position B.

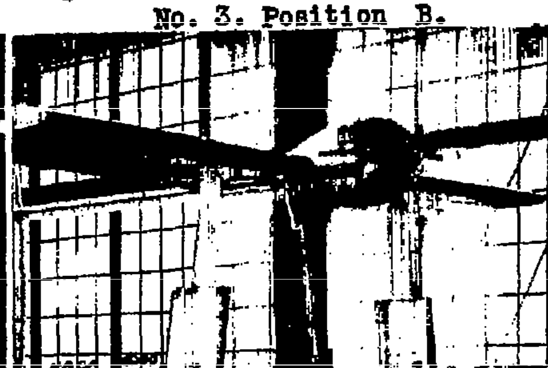


Fig. 8 Clark Y airfoil. Nacelle No. 1. Position B.

Fig. 9 Clark Y airfoil. Nacelle No. 1. Position C-3-B.

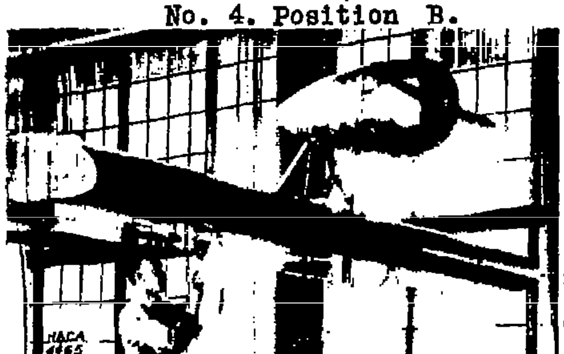


Fig. 10 Thick airfoil. Nacelle No. 4. Position B-2-A.

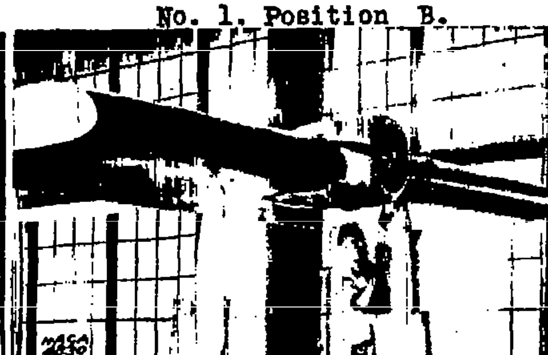


Fig. 11 Thick airfoil. Nacelle No. 4. Position B.

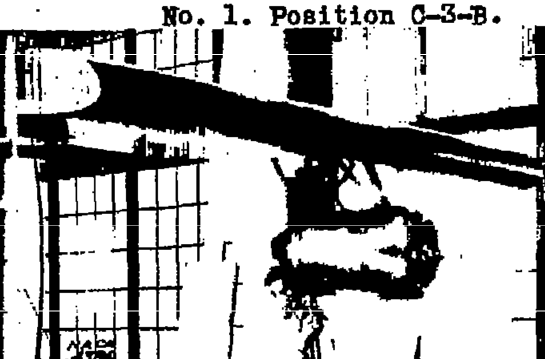


Fig. 12 Thick airfoil. Nacelle No. 4. Position B-2-B.

Various wing-nacelle combinations mounted for tests.

Figs.4,5,6,7,8,9,10,11,12.

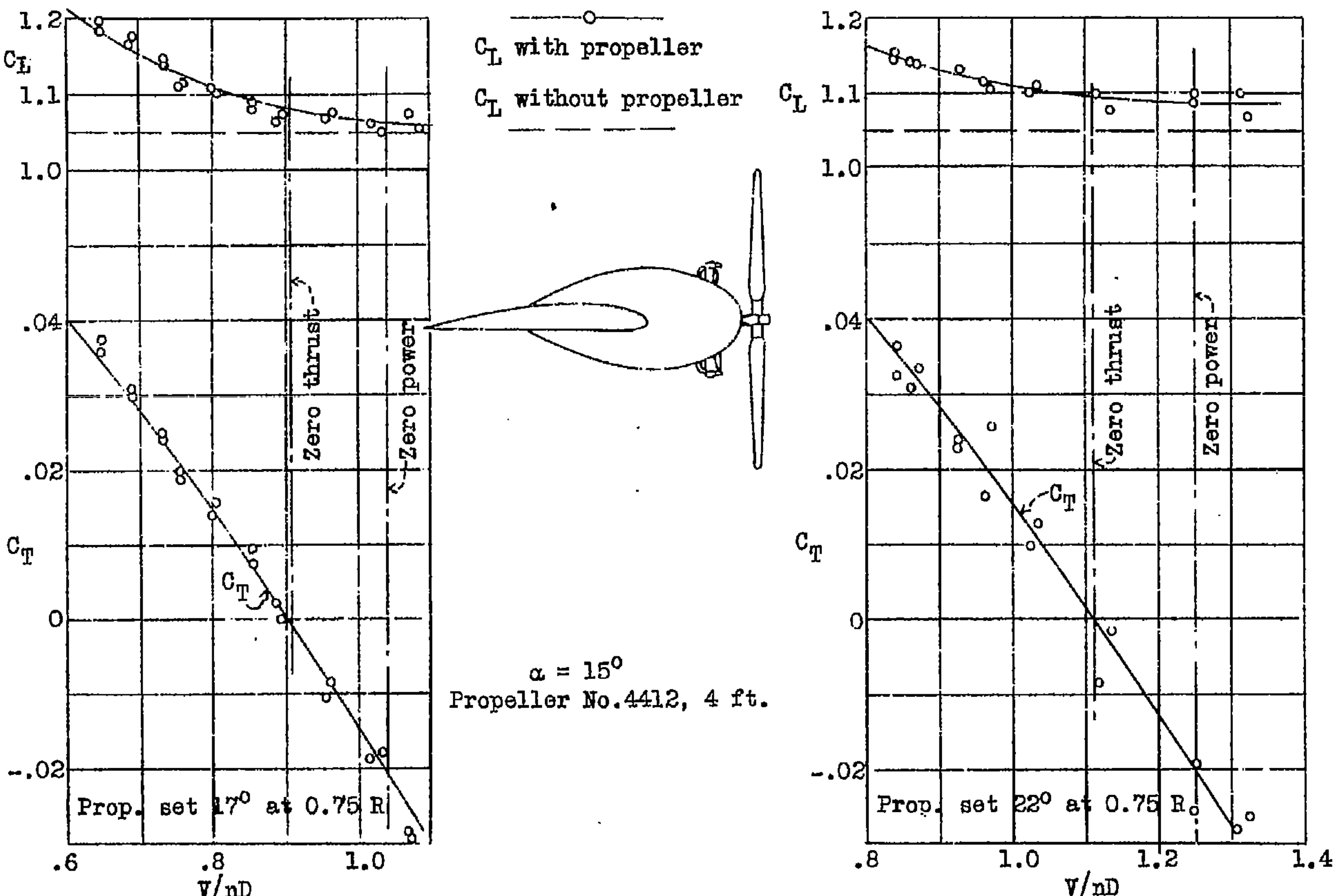
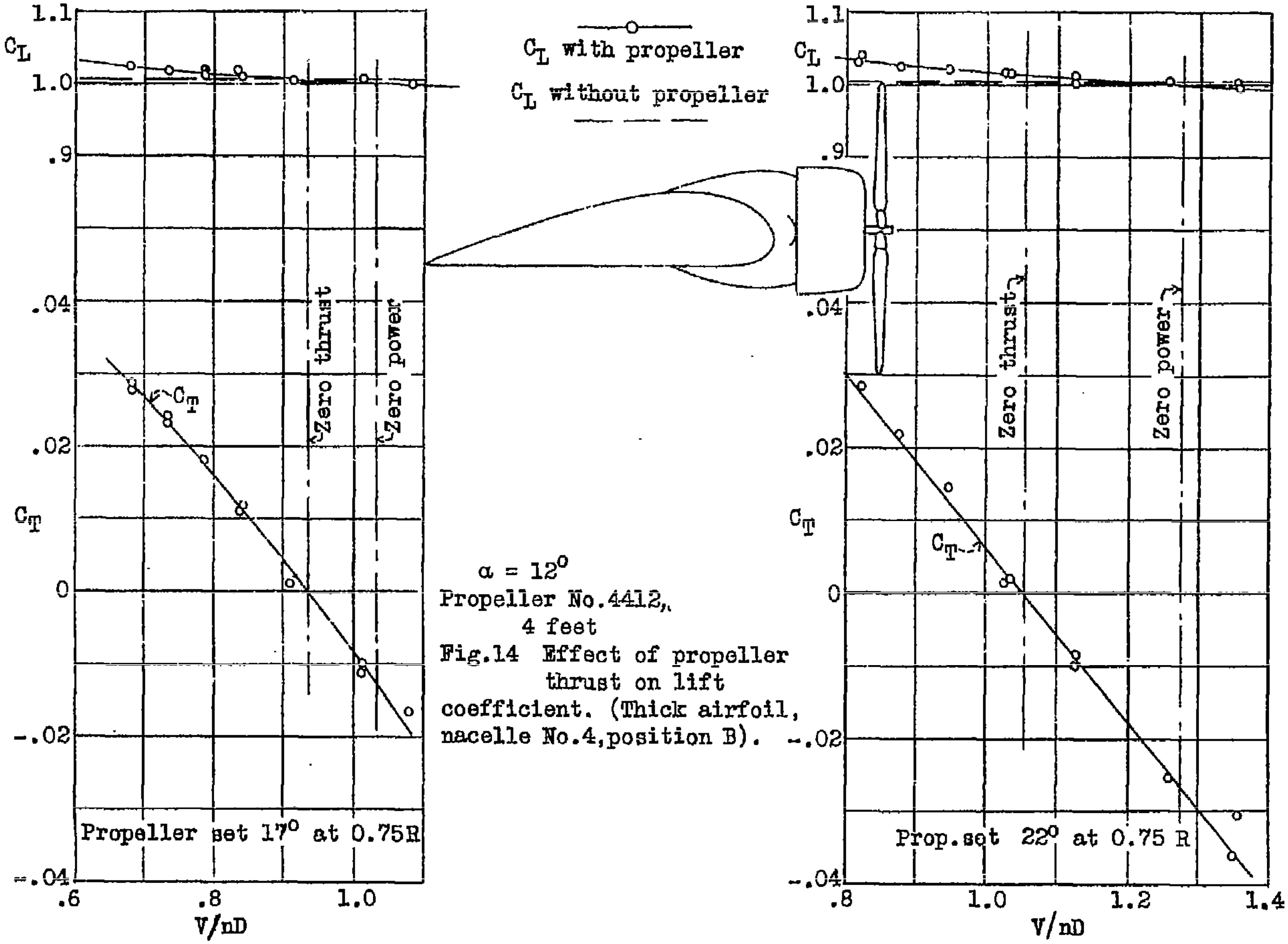
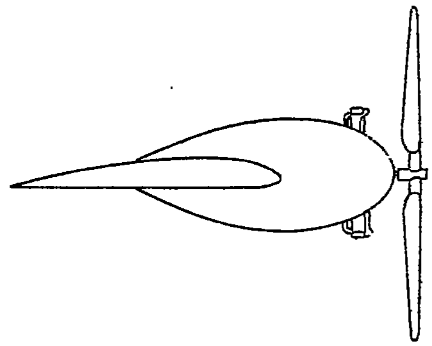


Fig.13 Effect of propeller thrust on lift coefficient.(Clark Y airfoil,nacelle No.2,position B).



α = 12°
Propeller No.4412,
4 feet
Fig.14 Effect of propeller thrust on lift coefficient. (Thick airfoil, nacelle No.4, position B).



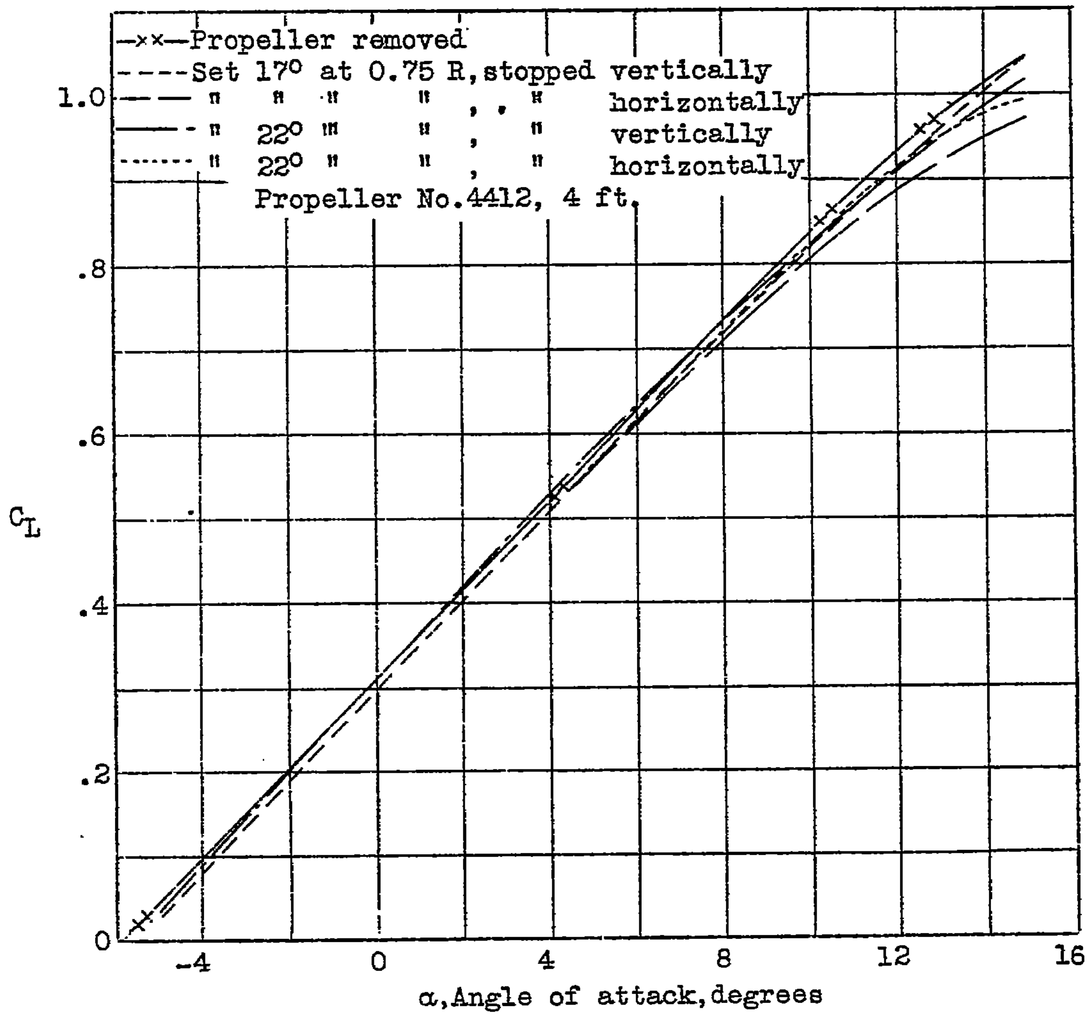


Fig.15 Effect of the lift coefficient of pitch and position of a stopped propeller. (Clark Y airfoil, nacelle No.2, position B).

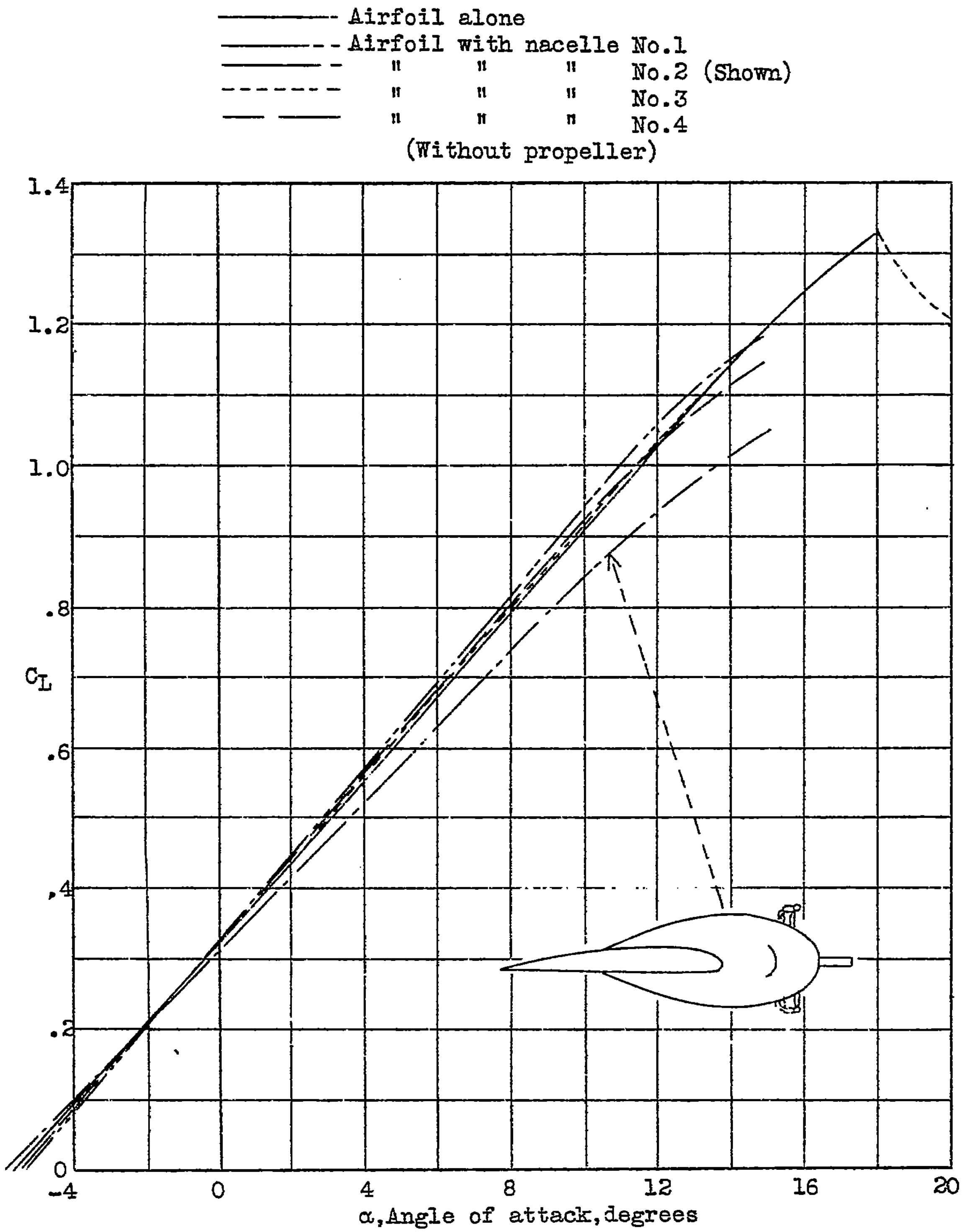


Fig.16 Effect of nacelles on lift coefficient. (Clark Y airfoil, position B).

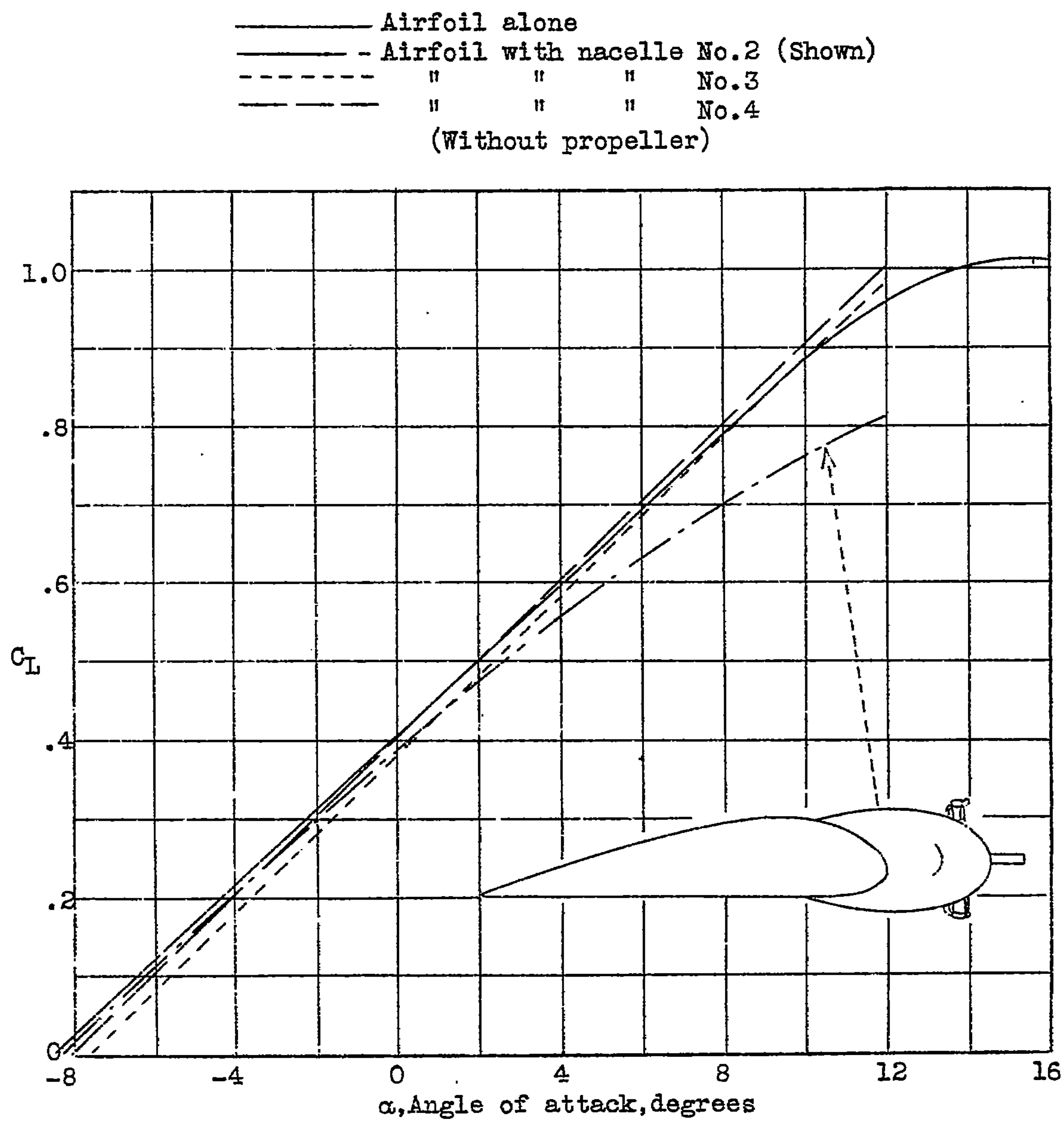


Fig.17 Effect of nacelles on lift coefficient. (Thick airfoil, position B).